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Homestead National Monument of America, Acoustic Monitoring Report, 2017

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U.S. Department of the Interior

Natural Resource Stewardship and Science

Homestead National Monument of America

Acoustic monitoring report - 2017

Natural Resource Report NPS/NRSS/NSNSD/NRR—2020/2083

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Data in this report were collected analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Executive Summary

This report presents acoustical data gathered by Student Conservation Association interns and the Natural Resource Specialist at Homestead National Monument of America in 2017. Data were collected at one site to provide park managers with information about the acoustical environment, sources of noise, and the existing ambient sound levels within the monument. This deployment also captured acoustic conditions during the total solar eclipse on 8/21/2017.[1]

In this deployment, sound pressure level (SPL) was measured continuously every second by a calibrated sound level meter. Other equipment included an anemometer to collect wind speed and direction and a digital audio recorder collecting continuous recordings to document sound sources. In this document, "sound pressure level" refers to broadband (12.5 Hz - 20 kHz), A-weighted, 1-second time averaged sound level ($L_{Aeq,\ 1s}$), and hereafter referred to as "sound level." Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 µPa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported in decibels (dB). A-weighting is applied to sound levels in order to account for the response of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz. For reference, Table 1 provides examples of sound levels measured in parks compared to sound levels of common sound sources.

Table 1. Sound level examples

Park Sound Sources	Common Sound Sources	Sound Level dB*
Volcano crater (HALE)	Human breathing at 3m	10
Leaves rustling (CANY)	Whispering	20
Crickets at 5m (ZION)	Residential area at night	40
Conversation at 5m (WHMI)	Busy restaurant	60
Cruiser motorcycle at 15m (BLRI)	Curbside of busy street	80
Thunder (ARCH)	Jackhammer at 2 m	100
Military jet at 100m AGL (YUCH)	Train horn at 1 m	120

* dB re 20 µPa A-weighted broadband (12.5 Hz—20 kHz), sound level measured over varied measurement durations and at the distances indicated.

Overall, existing ambient sound levels (L_{A50}) at the monument were measured to be 50.3 dB during the day to 56.5 dB at night. Table 2 reports the percent of time that measured levels at the monitoring locations were above four key sound level values. The first value, 35 dB ($L_{Aeq,\ 1s}$), addresses the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis et al. 2008). This level, 35

[1] Results of the eclipse monitoring effort are provided in Appendix B.

dB, is also the desired background sound level in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq,\,1s}$) (Berglund et al. 1999). The third value, 52 dB ($L_{Aeq,\,1s}$), is based on the EPA's speech interference level for speaking in a raised voice to an audience at 10 meters (EPA 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB ($L_{Aeq,\,1s}$), provides a basis for estimating speech interference on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Table 2**.** Time above metrics for HOME008.

Site ID	Frequency (Hz)	Time above sound level (% of daytime hours, 07:00 to 19:00)				Time above sound level (% of nighttime hours, 19:00 to 07:00)			
		35 dB*	45 dB*	52 dB*	60 dB*	35 dB*	45 dB*	52 dB*	60 dB*
HOME008	12.5-20,000	100.0	97.7	31.0	0.0	100.0	100.0	84.1	18.9
	20-1,250	30.3	0.8	0.1	0.0	7.6	0.2	0.0	0.0

* dB $L_{Aeq,\,1s}$ re 20 μPa

Sound levels are often measured over narrow frequency bands (typically in one-third octave bands between 12.5 Hz - 20 kHz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded key values in two frequency *ranges*. The top value in each split-cell of Table 3 uses the full frequency range (12.5 Hz - 20 kHz) collected, whereas the bottom value focuses on frequencies affected by low frequency noise sources (20-1,250 Hz). This Natural Sounds (NS) modification to A-weighting (referred to as ANS weighting, ANSI S3/SC1.100, 2014) eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 52 dB ($L_{Aeq,\,1s}$) level was exceeded at HOME008 31 % of the time during the day and 84 % of the time at night, but in the 20-1,250 Hz range, the 52 dB functional sound level value was very rarely or never exceeded in daytime or nighttime. Speech interruption occurs (between two people 1 meter apart) at 60 dB ($L_{Aeq,\,1s}$) and this level was never (or very rarely) exceeded at HOME008 during the day.

After data collection was complete, a trained technician calculated how often noise[2] sources were audible. See Methods section for protocol details, equipment specifications, and metrics calculations. Sound source analysis revealed that noise is audible about 72 % of the time at the study site when

[2]For the purposes of this document, we will refer to "noise" as any human-caused sound that masks or degrades natural sounds

averaged across all hours of the day (Table 3). This amount of noise audibility is consistent with previous acoustic inventories in the monument, which ranged from 70 – 91% depending upon site and season. The most common sources of noise during this study period was non-natural unknown, which was likely the nearby fertilizer factory. Natural sources such as wind, rain, thunder, birds, and insects were also commonly audible. Specifically, recordings of coyotes, barred owl, and thunder were collected during this monitoring period. Natural ambient sound levels (L_{Anat}) were measured to be 48.4 dB during the day and 55.2 dB at night. Increased natural ambient sound levels during the night were due to increased insect activity (see Figure 3 in the Results section).

Table 3. Mean time audible for human-caused noise, vehicles, and non-natural unknown, existing and natural ambient sound levels (dB re 20 μPa, A-weighted broadband,12.5 Hz—20 kHz) at HOME008 (where day is 7:00 – 19:00 and night is 19:00 – 7:00)

		Mean time audible for noise (% of 24 hour time period)			**Median Existing Ambient (L_{A50}) in dB**		**Median Natural Ambient (L_{Anat}) in dB**	
Site ID	**Season**	**All Noise**	**Vehicle**	**Non Natural Unknown**	**Day**	**Night**	**Day**	**Night**
HOME008	Summer	71.8	17.3	32.8	50.3	56.5	48.4	55.2

Acknowledgments

Acoustic data for this report was gathered by Jesse Bolli. Audibility analysis completed by D. Hanselmann.

Glossary of Acoustic Terms

Glossary of acoustic terms and definitions

Term	Definition
A-weighting	A-weighting is applied to sound levels in order to account for the sensitivity of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz.
Acoustic Environment	A combination of all the physical sound resources within a given area. This includes natural sounds and cultural sounds, and non-natural human-caused sounds. The acoustic environment of a park can be divided into two main categories: intrinsic and extrinsic.
Acoustic Resources	Includes both natural sounds like wind, water, & wildlife and cultural and historic sounds like tribal ceremonies, quiet reverence, and battle reenactments.
Amplitude	The relative strength of a sound wave, described in decibels (dB). Amplitude is related to what we commonly call loudness or volume.
ANS Weighting	The Natural Sounds (NS) modification to A-weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments.
Audibility	The ability of animals with normal hearing, including humans, to hear a given sound. It can vary depending upon the frequency content and amplitude of sound and by hearing ability of individual animals.
Decibel (dB)	A unit of sound energy. Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μPa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported as decibels (dB). Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy.
Existing ambient sound level (L_{A50})	sound level ($L_{Aeq,\ 1s}$) exceeded 50% of the time (50th percentile) for a specified duration. This level is referred to as the existing ambient sound level and the preferred metric for chronic conditions, as it is insensitive to infrequent loud events.
Frequency	Related to the pitch of a sound, and defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted ("weighted") to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable or hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.
Percentile sound levels (L_{A10}, L_{A50}, L_{A90})	Metrics used to describe A-weighted sound pressure levels (L), in decibels, exceeded 10, 50, and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L_{A50} value, while 90 percent of the time the measured levels are higher than the L_{A90} value, and 10 percent of the time measured levels are higher than the L_{A10} value.

Glossary of acoustic terms and definitions (continued)

Term	Definition
Day-Night average sound levels (L_{dn})	Day-Night Average Sound Level. Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.
Energy Equivalent Sound Level (L_{Aeq})	The sound energy level averaged over the measurement period. Generally, refers to A-weighted 1-second time averaged sound levels measured between 12.5 Hz - 20 kHz. This is a standard measurement collected using NSNSD acoustic monitoring protocol for sound level meters. Sound levels measured over 1 second intervals are used to calculate summary statistics, specifically percent of the time a sound level of interest is exceeded.
Natural Ambient Sound Level (L_{Anat})	The natural sound conditions in parks, which would exist in the absence of any human-caused noise sources. L_{Anat} is the preferred metric to represent baseline or reference conditions.
Noise Free Interval (NFI)	The length of the continuous period of time during which no human-caused sounds are audible.
Time Above	Within a defined time period, the percent of the time sound levels ($L_{Aeq,\ 1s}$) are above a specified sound level ($L_{Aeq,\ 1s}$). Commonly used levels are 35, 45, 52 dB ($L_{Aeq,\ 1s}$).
Time Audible	The amount of time that various sound sources are audible to humans with normal hearing, commonly expressed in percent of day, or percent of daytime hours and nighttime hours. A sound may be above natural ambient sound pressure levels, but still not audible. Similarly, some sounds that are below the natural ambient can be audible. Time Audible is useful because of its simplicity. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore, time audible is a protective proxy for wildlife. These data can be collected either by a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).
Sound Exposure Level (SEL)	The total sound energy of the actual sound during a specific time period. SEL is usually expressed using a time period of one second.
Sound Pressure	Minute change in atmospheric pressure due to passage of sound that can be detected by microphones.
Sound vs. Noise	Sound and noise are often used interchangeably to describe an acoustic source. A common definition of noise is unwanted sound or sounds that interfere with a signal of interest (Harris 1998; Templeton 1997). However, noise is not a purely subjective designation. Any sound that serves no function is noise. Most sounds produced by human transportation and other machinery are unintended and serve no function, therefore are noise regardless of the attitudes of the listener. While there are unintended sounds in nature, like the footfalls of an animal, these sounds provide vital cues for some receivers and are therefore considered sounds to the receiver, yet noise from the perception of the producer.
Soundscape	The human perception of physical sound resources.

Introduction

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing opportunities to experience natural quiet and the sounds of nature was a very important reason for having national parks, while another 23 percent thought that it was somewhat important (Haas & Wakefield 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald et al. 1995). Acoustical monitoring provides a scientific basis for assessing the status of acoustic resources, identifying trends in resource conditions, quantifying impacts from other actions, assessing consistency with park management objectives and standards, and informing management decisions regarding desired future conditions.

National Park Service Natural Sounds and Night Skies Division

The Natural Sounds and Night Skies Division (NSNSD) helps parks manage sounds in a way that protects park resources and the visitor experience. The NSNSD addresses acoustical issues raised by Congress, NPS Management Policies, and NPS Director's Orders. The NSNSD works to protect, maintain, or restore acoustical environments throughout the National Park System. Its goal is to provide coordination, guidance, and a consistent approach to soundscape protection with respect to park resources and visitor use. The program also provides technical assistance to parks in the form of acoustical monitoring, data processing, park planning support, and comparative analyses of acoustical environments.

Soundscape Planning Authorities

The National Park Service Organic Act of 1916 states that the purpose of national parks is "… to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." In addition to the NPS Organic Act, the Redwoods Act of 1978 affirmed that, "the protection, management, and administration of these areas shall be conducted in light of the high value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress."

Direction for management of natural soundscapes[3] is represented in 2006 Management Policy 4.9:

The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise), and will protect natural soundscapes from unacceptable impacts. Using appropriate management planning, superintendents will identify what levels and types of unnatural sound constitute acceptable impacts on park natural soundscapes. The frequencies, magnitudes, and durations of acceptable levels of unnatural sound will vary throughout a

[3] The 2006 Management Policy 4.9 and related documents refer to "soundscapes" instead of "acoustic resources." When quoting from this authority, it is advisable to note that the term often refers to resources rather than visitor perceptions.

park, being generally greater in developed areas. In and adjacent to parks, the Service will monitor human activities that generate noise that adversely affects park soundscapes [acoustic resources], including noise caused by mechanical or electronic devices. The Service will take action to prevent or minimize all noise that through frequency, magnitude, or duration adversely affects the natural soundscape [acoustic resource] or other park resources or values, or that exceeds levels that have been identified through monitoring as being acceptable to or appropriate for visitor uses at the sites being monitored (NPS 2006a).

It should be noted that "the natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated" (NPS 2006b). However, the desired acoustical condition may also depend upon the resources and the values of the park. For instance, "culturally appropriate sounds are important elements of the national park experience in many parks" (NPS 2006b). In this case, "the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established" (NPS 2006b).

Further guidance is provided in 2006 Management Policies 4.1.4 Partnerships, 4.1.5 Restoration of Natural Systems, 8.2 Visitor Use, 8.2.2 Recreational Activities, 8.2.3 Use of Motorized Equipment, and 8.4 Overflights and Aviation Uses (NPS 2006).

Directors Order 47, Preservation of the Acoustic Environment and Noise Management (2015) builds on the principles set out in Management Policies, but goes on to direct how and when to consider acoustic resources in park management. Through this order, parks are guided to manage noise by: identifying noise sources, minimizing noise from park operations, considering the acoustic environment in park planning documents, and promoting park sounds and noise management through communication, education, and outreach.

National Parks Air Tour Management Act (NPATMA) was passed on April 5, 2000 to regulate commercial air tour operations for each unit of the National Park System, or abutting tribal land, where such operations occur or are proposed. The Act required the Federal Aviation Administration (FAA), in cooperation with the NPS, to develop an Air Tour Management Plan (ATMP) for each unit of the National Park System to provide acceptable and effective measures to mitigate or prevent the significant adverse impacts, if any, of commercial air tour operations upon natural and cultural resources and visitor experiences. In 2012, NPATMA was amended to allow the FAA and NPS to enter into voluntary agreements with a commercial air tour operator as an alternative to an ATMP.

Study Area

This report covers results from an acoustic inventory conducted in 2017 at HOME008, but the same acoustic monitoring system was deployed seven times at 4 different sites in the park during 2011 and 2012 (Table 4). Sites HOME001 and HOME003 were chosen because of potential plans for an outdoor education classroom and for their proximity to Highway 4. Site HOME002 was chosen due to its proximity to the historic Freeman School and Highway 4. Site HOME004 was chosen as a representative of the woodland area located further from Highway 4. HOME008 was an ideal location for collecting data during the 2017 eclipse because it was located far from centers of human activity like the visitor centers. Figure 1 shows the location of acoustic inventory sites in map format.

Table 4. Metadata for each season of acoustical monitoring

Site	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
HOME001	South of fire ring	8/11/2011-9/9/2011	Riparian area, deciduous forest	376	40.29030	-96.83520
HOME001	South of fire ring	12/21/2011-1/12/2012	Riparian area, deciduous forest	376	40.29030	-96.83520
HOME002	Freeman School	9/10/2011-10/12/2011	Grass	384	40.29278	-96.84254
HOME003	Picnic Area	11/3/2011-12/02/2011	Riparian area, deciduous forest	391	40.29129	-96.83483
HOME003	Picnic Area	6/22/2012-7/15/2012	Riparian area, deciduous forest	391	40.29129	-96.83483
HOME004	Cottonwood Tree	3/28/2012-4/12/2012	Deciduous forest	381	40.28622	-96.83797
HOME004	Cottonwood Tree	9/14/2012-10/9/2012	Deciduous forest	381	40.28622	-96.83797
HOME008	South Woodland	8/12/2017-9/11/2017	Riparian	388	40.28526	-96.83923

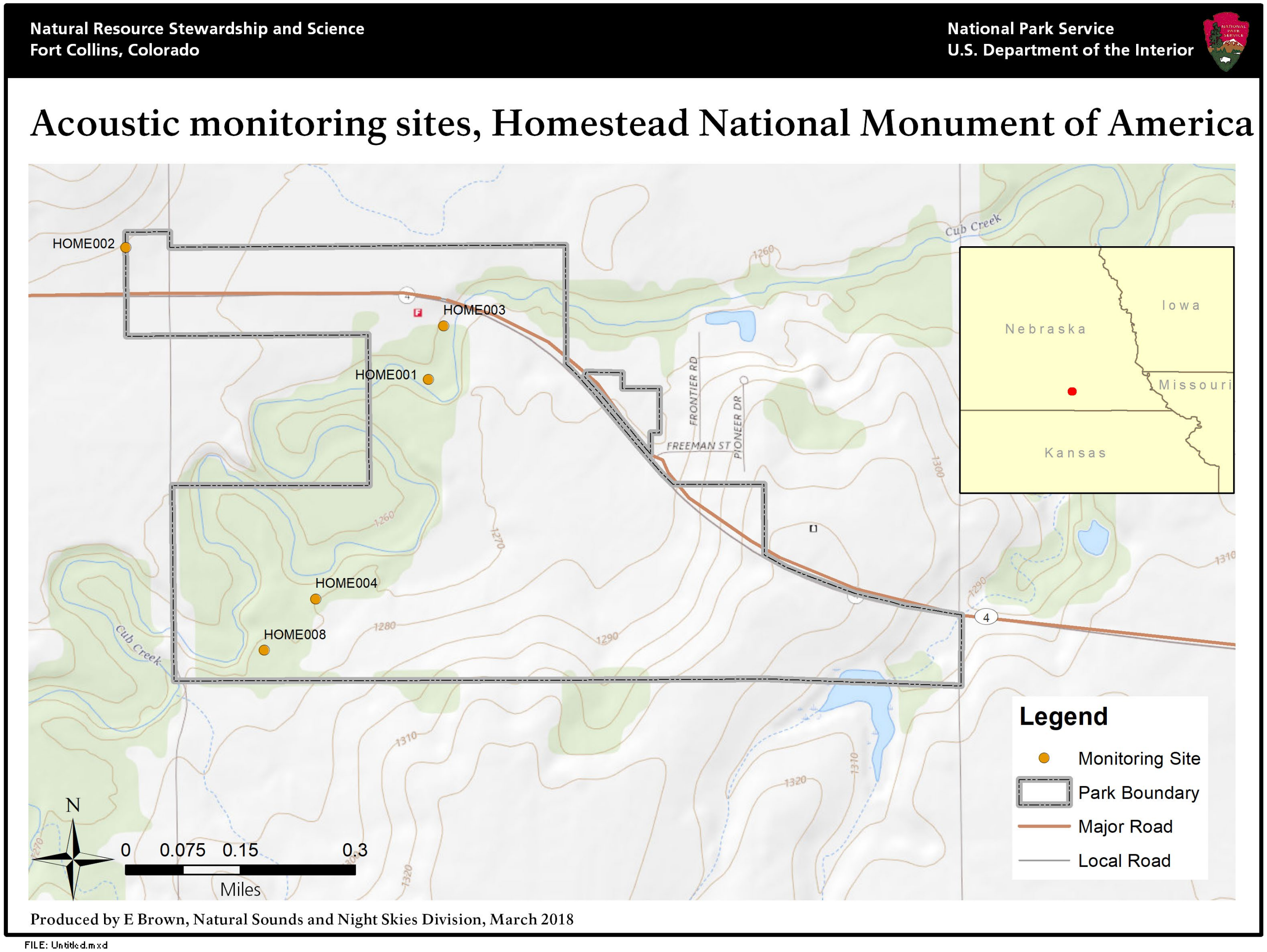

Figure 1. Location of monitoring sites

Methods

Automatic Monitoring

A Larson Davis 831 sound level meter (SLM) was deployed at this monitoring site. The Larson Davis SLM is a hardware-based, real-time analyzer which constantly records sound pressure level (SPL) and one-third octave band data. This Larson Davis-based site met American National Standards Institute (ANSI) Type 1 standards. The sound level meter provided the information needed to calculate metrics described below in Calculation of Metrics.

Acoustical monitoring equipment is used by many industries to determine noise levels in different environments, both indoors and outdoors. NPS uses equipment that is similar to the equipment used by other industries, but has developed a unique configuration that stands up to the potentially hash environment encountered in national parks. The microphone with environmental shroud was set up on a tripod at 1.5 m, which is an approximation of the average height of the human ear. The digital audio recorder recorded continuous audio through the entire monitoring period. An anemometer was attached to a tripod and placed approximately 10 feet from the microphone, to capture local wind conditions without recording possible sound from anemometer wind cup rotation.

The sampling station consisted of:

- Type 1 sound level meter
- Microphone with environmental shroud
- Preamplifier
- 12 V battery pack
- Anemometer (wind speed and direction)
- Digital audio recorder

The sampling station collected:

- A-weighted 1 second time averaged sound level ($L_{Aeq,\ 1s}$) in dB re 20 µPa
- Continuous digital audio recordings
- One-third octave band data every second ranging from 12.5 Hz – 20,000 Hz
- Continuous meteorological data for wind speed

Monitoring Period

The monitoring period lasted approximately 29 days. NSNSD has determined that 25 day monitoring periods during opposing seasons allow the data to capture seasonal difference that occur at each site within a reasonable margin of error (NPS 2005).

Calculation of Metrics

The status of the acoustical environment can be characterized by sound level (L_{A50}, L_{Anat}, L_{A90}, L_{A10}, L_{Aeq}) and frequency content, and event durations (through off-site listening). NPS uses descriptive figures and metrics to interpret these characteristics.

Two fundamental descriptors are existing ambient (L_{A50}) and natural ambient (L_{Anat}) sound levels. These are both examples of percentile levels, where each L_x value refers to the sound level that is exceeded x% of the time. The L_{A50} represents the median sound level, and is drawn from a full dataset (removing data with wind speed > 5m/s to eliminate error from microphone distortion). The $L_{A50}$is the preferred metric to represent prevailing acoustic conditions. The natural ambient (L_{Anat}) is an estimate of what the sound levels for a site would be if all human-caused noise sources were removed. L_{Anat} is the preferred metric to represent baseline or reference conditions.

For a given hour (or other specified time period), L_{Anat} is calculated to be the sound level exceeded x percent of the time, where x is defined by equation (1):

$$x = \frac{100 - P_H}{2} + P_H, \tag{1}$$

P_H is the percentage of samples containing noise for the hour. For example, if human caused sounds are present 30% of the hour, x = 65, and the L_{Anat} is equal to the L_{65}, or the level exceeded 65% of the time. To summarize and display these data, the median of the hourly L_{Anat} values for the daytime hours (0700-1900) and the median of the hourly L_{Anat} values for the nighttime (1900-0700) are displayed in Figure 4 in the results section.

Off-Site Listening

Off-site listening is normally done by listening to an audio recording and simultaneously visually analyzing a spectrogram (for more information on Listening Center software, see Appendix C). Auditory analysis was used to calculate the audibility of sound sources at the monitoring locations. Trained technicians at HOME (Figure 2) listened to a subset of .mp3 audio samples (10 seconds every two minutes for eight days of audio) in order to identify durations of audible sound sources. The total percent time noise was audible was then used to calculate the natural ambient sound level (L_{Anat}) for each hour (see Equation 1 above for more information). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustical environment. For the complete results of this thorough audibility analysis, see Table 6 and Table 7.

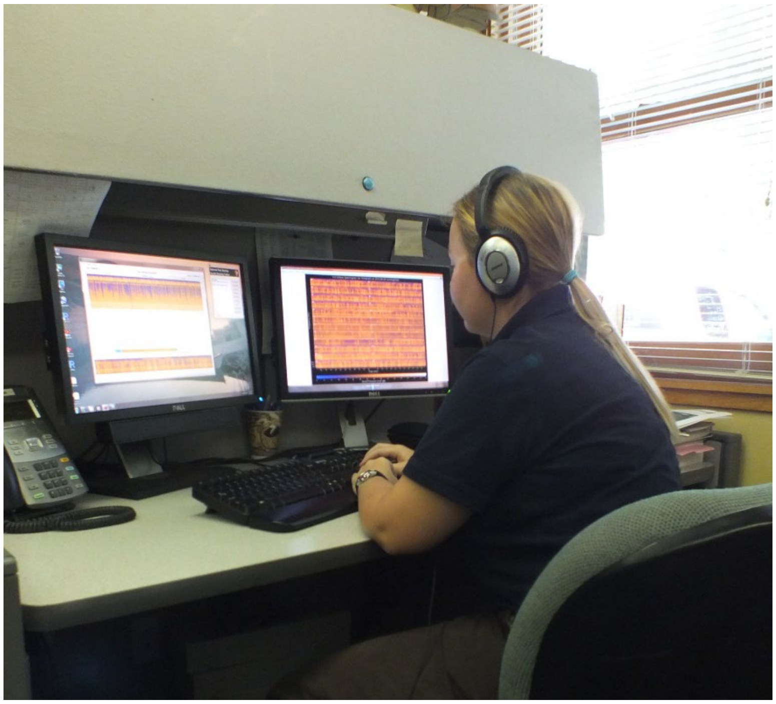

Figure 2. SCA intern Kelly Manktelow identifies sound sources using Acoustic Monitoring Toolbox (NPS) software

Results

Frequency content

In order to determine the effect that noise has on the acoustical environment, it is useful to examine percentile metrics across a frequency range. High frequency sounds (such as a cricket chirping) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 smaller ranges, each encompassing one-third of an octave. These smaller bands closely represent how humans distinguish between frequencies of sound. For each one-third octave band, sound level ($L_{eq,\ 1s}$) was recorded once per second for the duration of the monitoring periods. The percentile sound levels for 33 one-third octave band frequencies over the day and night periods are shown in Figure 3.

Examining the sound energy in each one-third octave band (combined with digital audio recordings) allows acoustic technicians to determine what types of sounds are contributing to the overall sound levels at a site. The grayed area of Figure 3 represents sound levels outside of the typical range of human hearing. The percentile levels (L_x) are also shown for each one-third octave band. They represent the sound levels exceeded x percent of the measurement period. For example, L_{90} is the sound level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the sound level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10}. The bold portion of the column represents the difference between L_{50} and L_{nat}. The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing sound levels at this site. The size of this portion of the column is directly related to the percent time that human caused sounds are audible. When bold portions of the column do not appear the natural and existing sound levels were either very close to each other, or were equal. The typical frequency levels for transportation, conversation, and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species-, or habitat-specific.

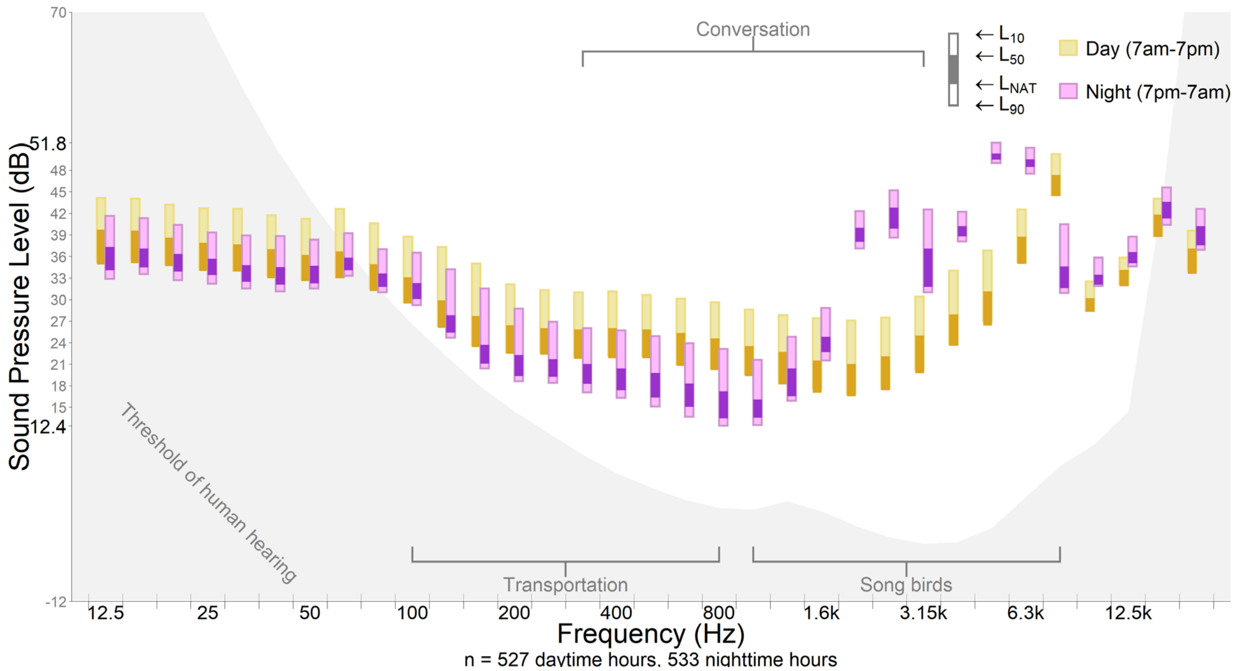

Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at HOME008

Sound level: Time Above

To understand how acoustic conditions in the park might affect visitors, measured sound levels are compared to established sound levels. Specifically, Table 5 reports the percent of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional values during the monitoring periods (daytime and nighttime). The top value in each split-cell uses the full frequency range, whereas the bottom values report the percent of time ANS-weighted sound levels (20-1,250 Hz) are above functional values. Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. ANS weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 52 dB ($L_{Aeq, 1s}$) level was exceeded at HOME008 31 % of the time during the day and 84 % of the time at night, but in the 20-1,250 Hz range, the 52 dB functional sound level value was very rarely or never exceeded in daytime or nighttime (Table 5).

The first functional value in Table 5 is 35 dB ($L_{Aeq,1s}$), which is designed to address the health effects of sleep interruption. Studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002). The second sound level value, 45 dB ($L_{Aeq,1s}$), addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq,1s}$) (Berglund et al. 1999). The third sound level value, 52 dB ($L_{Aeq,1s}$), is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB ($L_{Aeq,1s}$), provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Table 2. Time above metrics for HOME008.

Site ID	Frequency (Hz)	Time above sound level (% of daytime hours, 07:00 to 19:00)				Time above sound level (% of nighttime hours, 19:00 to 07:00)			
		35 dB*	45 dB*	52 dB*	60 dB*	35 dB*	45 dB*	52 dB*	60 dB*
HOME008	12.5-20,000	100.0	97.7	31.0	0.0	100.0	100.0	84.1	18.9
	20-1,250	30.3	0.8	0.1	0.0	7.6	0.2	0.0	0.0

* dB $L_{Aeq,\ 1s}$ re 20 μPa

Sound Level: Percentile Levels

To understand the range of acoustic conditions at the park, percentile sound levels are reported (Figure 4). In Figure 4, the A-weighted percentile sound levels (L_{A90}, L_{Anat}, L_{A50}, and L_{A10}) for HOME008 are shown. The hourly percentile sound levels are calculated from the broadband (12.5 Hz - 20 kHz) A-weighted, 1-second time averaged sound levels ($L_{Aeq,\ 1s}$) within each hour of the day. For instance, in Figure 4, the L_{A50} (median) sound level for HOME008 during the 6:00 hour is 52.5 dB. On the other hand, the sound level exceeded 10% of the time (L_{A10}) for the same hour at this site is 54 dB, meaning 90% of the measurement period is quieter. In other words, 90% of the measurements are quieter. High percentile sound levels in the late evening and early morning hours are largely due to insect activity (Figure 4). Hours where the L_{A50} and the L_{Anat} differ the most are usually hours with the most human-caused noise (in this case, 6:00 – 20:00).

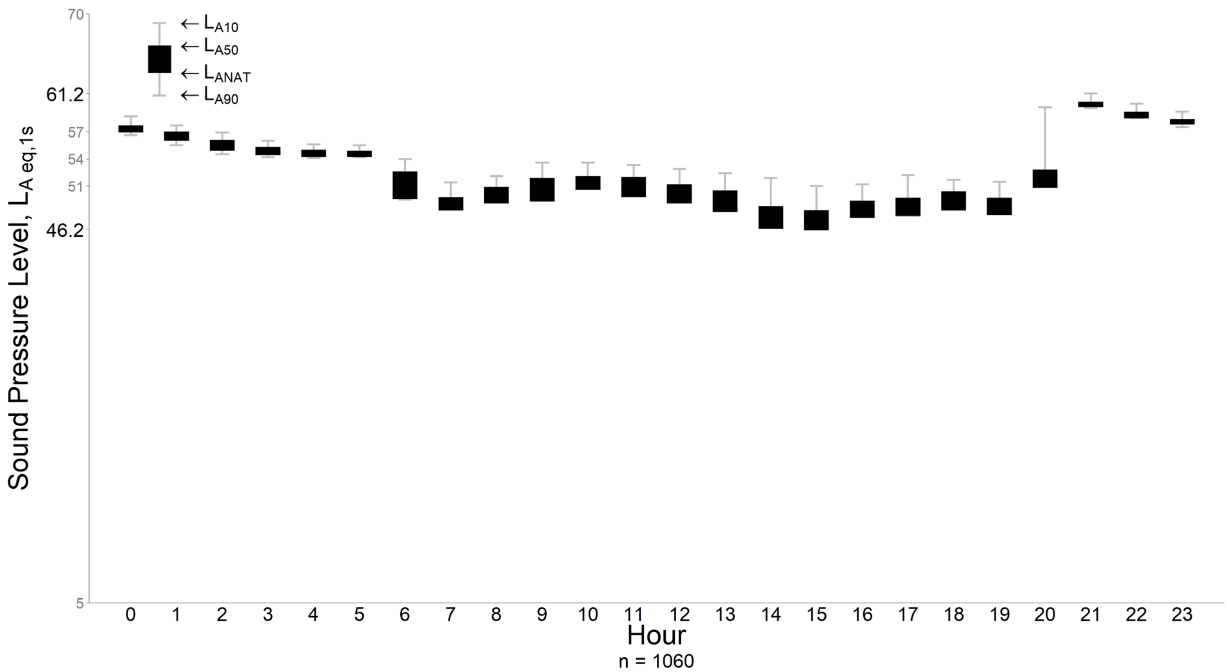

Figure 4. Median percentile sound levels ($L_{Aeq,\,1s}$), in dB re 20 μPa, at HOME008

Event duration

Through off-site listening analysis, event duration for all audible sounds is calculated. Table 6 and Table 7 list audible natural sounds and noise sources at HOME008. Mean hourly audibility was calculated over eight days of analysis. See Appendix A for more information on analysis procedures. Figure 5 displays hourly audibility for all non-natural sources, as compared to audibility of two noise sources of interest: aircraft and vehicles.

Table 3. Mean hourly time audible (%) for each natural sound source at HOME008, n=8 days

Sound Source	**00h**	**01h**	**02h**	**03h**	**04h**	**05h**	**06h**	**07h**	**08h**	**09h**	**10h**	**11h**	**12h**	**13h**	**14h**	**15h**	**16h**	**17h**	**18h**	**19h**	**20h**	**21h**	**22h**	**23h**
Wind	45.0	52.5	51.3	47.1	39.6	43.3	32.5	30.0	35.8	47.9	51.7	65.0	68.8	64.6	84.6	75.4	81.7	69.6	72.5	62.1	45.8	15.0	31.7	41.7
Water	0.0	0.0	3.8	0.4	0.0	3.8	12.1	18.3	11.3	11.7	11.7	11.3	10.4	11.7	7.1	5.0	2.9	0.4	0.8	0.0	0.0	0.0	0.0	0.0
Rain	0.0	0.0	2.5	0.0	0.0	0.0	0.8	12.5	12.5	12.5	7.9	10.4	7.9	2.9	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	7.5
Thunder	4.6	5.0	2.9	1.2	0.4	2.1	4.6	6.7	2.1	0.0	0.4	2.9	0.8	4.2	0.4	2.9	1.7	0.8	0.8	0.0	0.0	0.0	8.7	11.3
Mammal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.4	0.0	0.0	0.0	0.0	0.0
Squirrel	0.0	0.0	0.0	0.0	0.0	0.0	4.2	7.5	4.2	4.6	5.0	2.1	4.2	1.7	4.2	3.3	3.3	7.9	10.0	12.5	4.6	0.0	0.0	0.0
Coyote	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Bird	12.5	5.8	9.6	10.0	12.1	17.9	92.5	87.5	88.7	96.2	83.7	78.3	71.7	64.6	59.6	60.0	54.6	52.1	52.9	60.4	35.0	6.2	5.4	3.3
Amphibian	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Insect	100	100	100	100	100	100	100	87.5	87.1	97.9	100	99.2	99.6	97.1	97.5	99.2	100	100	99.6	99.6	100	100	100	99.6
Natural Unknown	1.7	0.8	2.9	1.7	2.9	1.7	2.9	2.1	4.2	2.9	7.1	5.8	5.8	2.5	3.3	3.8	3.3	2.9	2.5	3.3	4.2	3.8	3.3	2.1

Table 4. Mean hourly time audible (%) for each noise source at HOME008, n=8 days

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Aircraft	3.3	12.1	8.7	5.4	12.1	10.0	7.5	11.3	13.8	12.9	15.8	18.3	25.0	24.6	17.1	12.9	14.2	15.0	12.1	12.9	9.6	0.4	2.5	3.8
Jet	2.5	4.6	3.3	3.3	6.7	3.8	5.0	7.9	10.4	16.3	15.0	14.6	19.2	16.3	19.6	15.8	20.4	17.9	22.9	22.5	16.7	7.1	8.7	8.3
Propeller Aircraft	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle	12.1	12.1	6.2	15.0	11.3	19.6	31.2	35.4	31.7	18.3	22.5	16.3	14.2	15.8	12.9	12.1	15.4	22.1	12.9	22.9	17.1	10.4	14.2	14.6
Automobile	6.2	0.4	5.0	3.8	1.7	0.4	1.2	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alarm, Horn	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0
Motorcycle	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Truck	2.5	1.7	2.1	1.7	0.4	5.0	15.4	23.7	10.0	9.6	8.3	8.7	11.7	7.9	6.2	9.6	7.9	8.7	6.2	5.0	3.3	1.7	0.4	0.4
Heavy Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Train Whistle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lawnmower	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Voices	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.7	12.9	12.5	11.7	10.0	11.7	10.4	4.6	7.5	2.5	0.0	0.8	0.0	0.0	0.0	0.0	0.0
Dog	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-Natural Unknown	17.5	22.5	26.2	28.3	32.1	28.7	24.2	17.9	30.4	40.4	38.3	35.4	23.3	28.3	42.9	45.4	43.3	35.8	40.8	39.2	41.7	32.9	34.2	36.7
All non natural	43.3	50.8	50.0	56.7	60.8	65.4	78.3	80.8	87.9	85.8	83.3	82.9	82.9	80.0	82.1	81.2	82.1	83.7	81.2	82.5	77.5	49.2	57.9	57.1

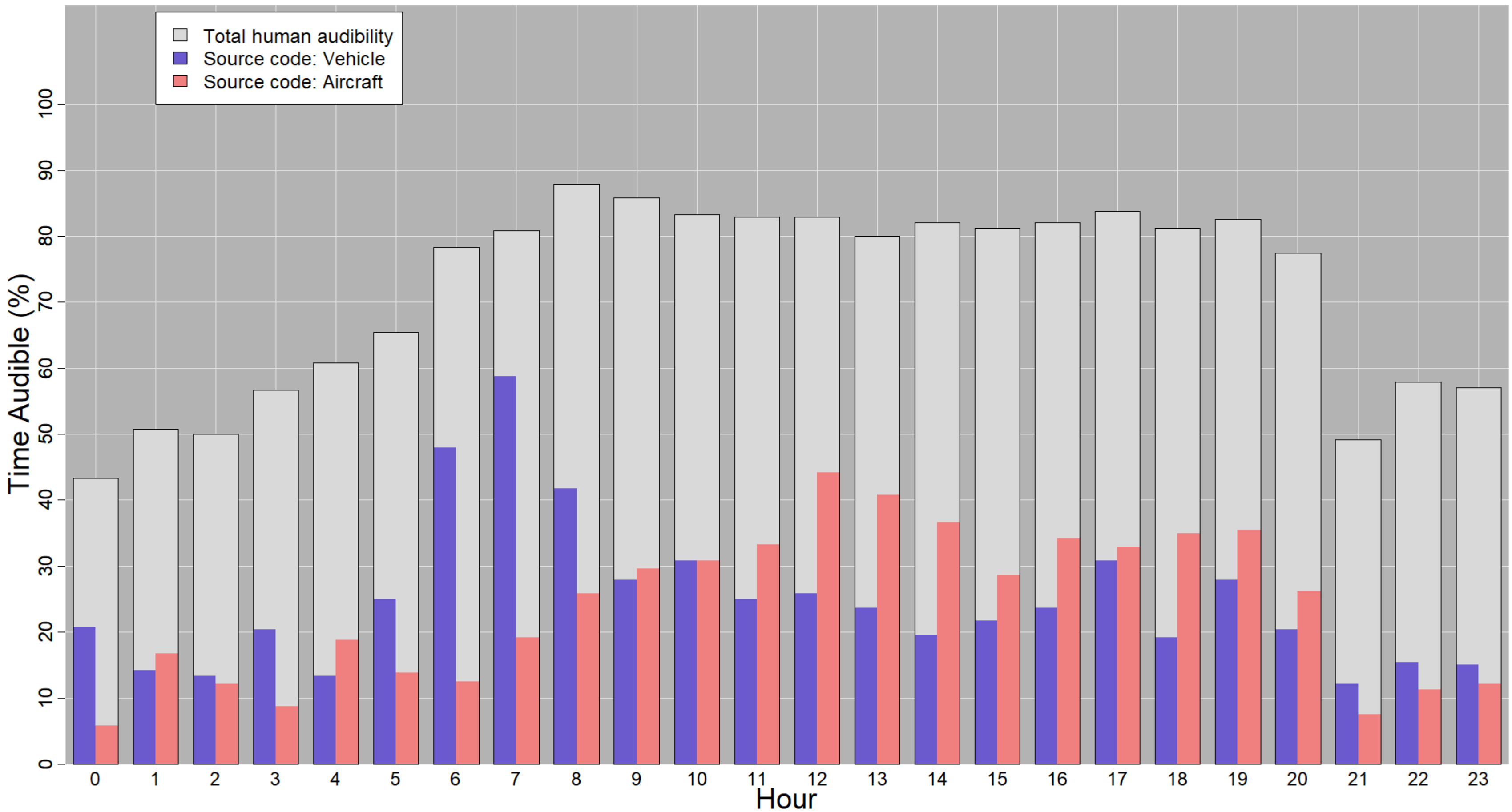

Figure 5. Hourly time audible for airplane, vehicle, and all noise sources at HOME008.

Conclusions

Acoustic monitoring allows parks to gain insight into levels of extrinsic noise and biologic activity. The results can help estimate the effects of noise on park visitors and wildlife alike. The study was successful in determining the acoustical conditions at Homestead National Monument of America (HOME) in a wooded area near Cub Creek in 2017.

Results from HOME008 included measures of existing ambient sound levels, calculations of sound source audibility through off-site listening, and estimates of natural ambient levels. Sound source analysis revealed that noise is audible about 72 % of the time at the study site when averaged across all hours of the day. In previous monitoring efforts at HOME, noise was audible on average between 70 – 91 % of the time, depending upon year, season, and site location. A non-natural unknown noise source was the most commonly heard noise during the 2017 monitoring period at HOME008, with a 24-hour mean audibility of 32.8 % (Table 7). It was not described by the listener in the analysis files, but it was likely related to the nearby fertilizer factory, which was a prominent noise source in the 2011-2012 study period, and was categorized as "non-natural other" during that analysis process.

Vehicles were the second most commonly heard noise source during the 2017 monitoring period at HOME008, with a 24-hour mean audibility of 17.3 %, but was as high as 35% during the 7:00 hour. During the 2011 – 2012 monitoring period, vehicles were the most frequently heard noise source across all sites and seasons. During summer daytime hours (8 am to 5 pm) at HOME001 and HOME003, music from the education center was often audible, but its presence was not noted in 2017 because HOME008 is about 0.45 miles (0.72 km) from the education center. Natural sources such as wind, rain, thunder, birds, and insects were commonly audible at HOME008 in 2017. Specifically, recordings of coyotes, barred owl, and thunder were collected during this monitoring period.

During the study period, natural ambient sound levels were measured to be 48.4 dB (L_{Anat}) during the day and 55.2 dB (L_{Anat}) at night. Insects contributed a significant amount of energy to the acoustic environment as night, as shown in Figure 3, as particularly high sound levels above 1.6 kHz. Existing sound levels (encompassing natural and noise sources) were measured to be 50.3 dB (L_{A50}) during the day and 56.5 dB (L_{A50}) at night. During the 2011-2012 monitoring period across all sites, existing sound levels were measured to be 38.4 dB – 53.6 dB (L_{A50}) during the day, and 34.9 dB – 59.0 dB (L_{A50}) at night.

For a broader context for the acoustic conditions at HOME, a comprehensive 1982 study of noise levels in residential areas found that nearly 87% of US residents were exposed to day-night sound levels (L_{dn}) over 55 dB, and an additional 53% were exposed to L_{dn} over 60 dB (EPA 1982). Note that noise levels have increased nationally with population growth since the EPA study (Suter 1991; Barber et al. 2010). Additionally, a nationwide study modeling daytime summer sound levels indicated that only 23 % of the continental United States was predicted to have an existing ambient sound level above 40 dB ($L_{A50,\ 12\ hr}$), and only 1% of the continental U.S. was predicted to have an existing daytime ambient sound level above 50 dB ($L_{A50,\ existing}$) (Mennitt 2013). Consider, though, that daily sound levels reported in this report for HOME008 can be influenced by both natural and non-natural sources.

Based on the results of this study, visitors to HOME are unlikely to experience a significant noise-free interval near the monitoring site, though noise is audible less in the early morning and late evening hours (Figure 5, Table 7). Noise has the potential to affect a visitor's experience in parks by causing annoyance (Rapoza et al. 2015), reducing the perceived scenic beauty (Weinzimmer et al. 2014), or simply by limiting opportunities for solitude. Increased sound levels may also have wide ranging effects on wildlife such as reduced predatory success (Mason 2015), changes in vocal communication, or increased vigilance by keystone species (Shannon et al. 2014). In a review of literature addressing the effects of noise on wildlife published between 1990 and 2013, wildlife responses to noise were observed beginning at about 40 dB ($L_{Aeq,\,x}$).[4] Of the papers reviewed, 20% showed impacts to terrestrial wildlife at or below noise levels of 50 dB ($L_{Aeq,\,1s}$) (Shannon et al. 2015).

The information presented in this report will be used to inform park managers and planners when they make management decisions, but it will also serve as a permanent record of what the park sounded like in 2017. Sound level data as well as continuous digital audio recordings will be stored at the Natural Sounds and Night Skies Division office in Fort Collins, Colorado for archiving purposes. In addition, during the 2017 monitoring period a separate monitoring system was deployed as part of a nationwide eclipse monitoring project. This unique data set measured acoustic conditions before, during, and after the total solar eclipse on August 21, 2017. Results of that study are provided in Appendix B.

[4] This metric is a composite of multiple metrics with varying time averaging metrics.

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Appendix A: Office Listening

Office listening is a way to characterize the length and type of noise events occurring at a monitored site (Figure 6). The NSNSD protocol calls for 8 days of analysis per monitoring period. The Acoustical Monitoring Toolbox splits the audio files in to 10 second clips every two minutes per one day. This results in 16 hours worth of data being analyzed per site. Each sound is assigned a number which is then put into the Listening Center program each time the listener hears the sound. These numbers are eventually used to calculate the LA_{nat} for the site.

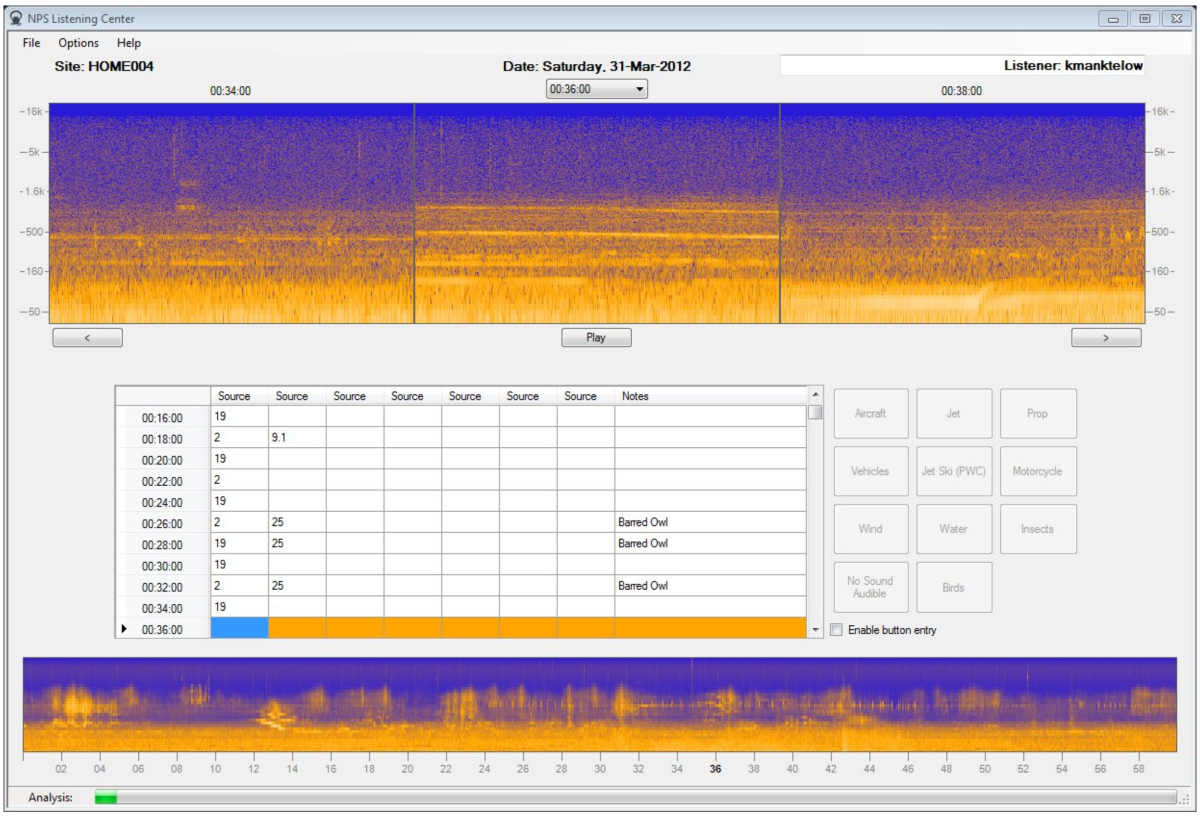


Figure 6. Screen shot of Listening Center. Three ten second samples are displayed side by side. Audible sound sources and annotations are recorded in the spreadsheet cells below.

Appendix B. Results of eclipse monitoring

Background

A total solar eclipse swept across the US on August 21, 2017 and awed millions of viewers. The path of totality crossed 21 national park units and 7 national trails. The Natural Sounds and Night Skies Division (NSNSD) of NPS partnered with 16 park units to deploy 29 acoustic recording systems before, during, and after the total solar eclipse on August 21, 2017. This national effort captured the sounds of the eclipse and offered an unique opportunity to measure how the eclipse changed the soundscape. The 14 parks (18 sites) with data spanned the continental US and included a diversity of habitats– from the plains of the midwest to the swamps of Congaree (Figure 7). Two parks (3 sites) were not in the path of totality.

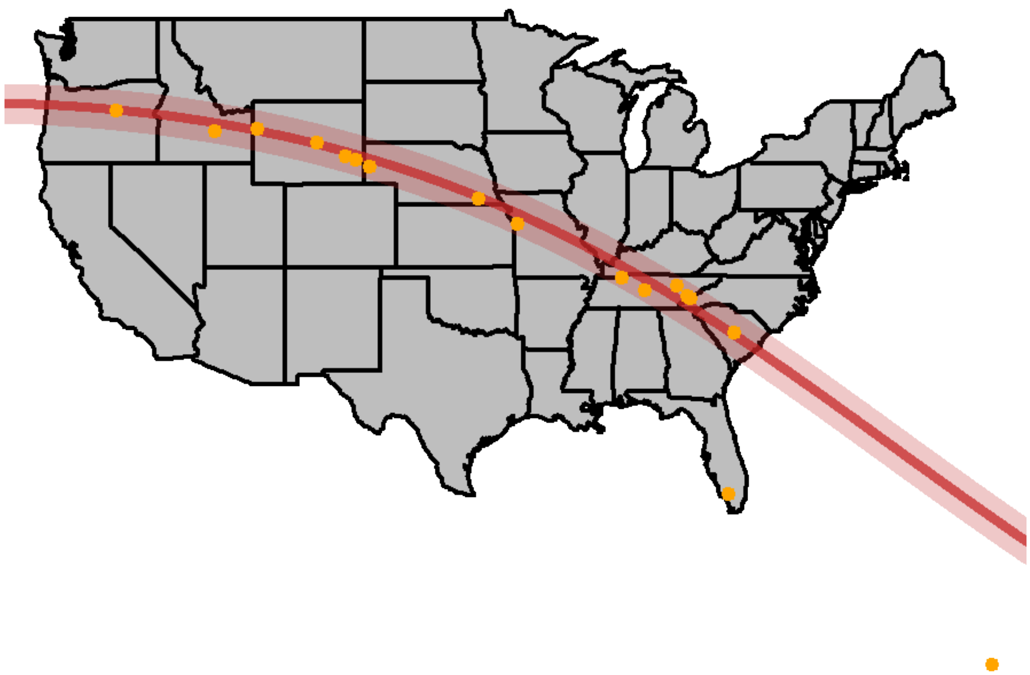


Figure 7. Locations of acoustic monitoring stations deployed during the solar eclipse.

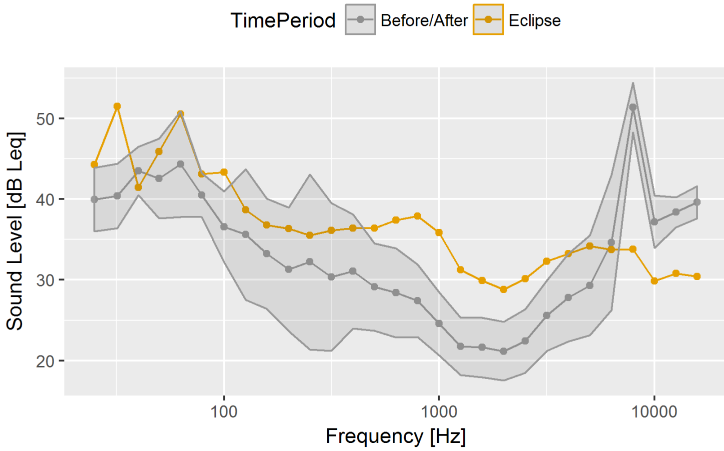
Data Collection

At HOME, one acoustic monitoring sites was deployed (40.29N 96.83W) from 18 August to 24 August (Figure 8). This was a frontcountry site in a temperate broadleaf/mixed habitat. At this site totality began at 18:02 GMT and lasted for 2min 34sec.

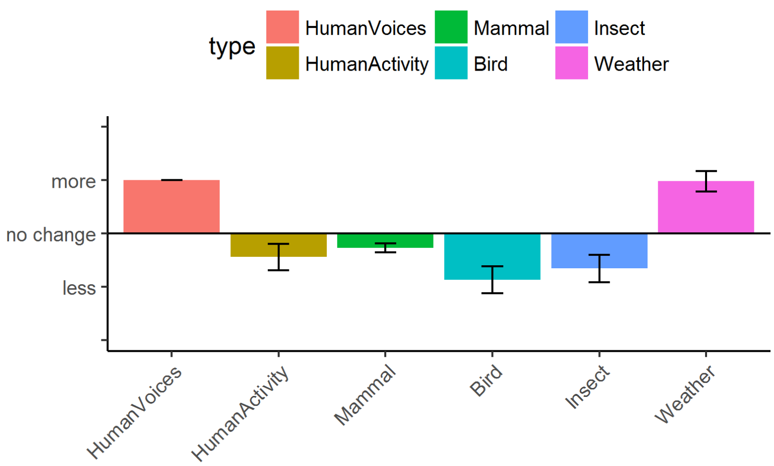
Figure 8. Bioacoustic monitoring station in Homestead N.M.

Data Analysis

Acoustic data during the time of totality for all days was extracted using automated scripts. To see if the soundscape changed, sound levels (at different frequencies) during totality were compared to all other days at the same time (Figure 9A). Google Form surveys were developed by NSNSD in which NPS participants listened to five different unidentified sound clips to determine what types of sounds were present or not present during the eclipse. A total of 312 sound clips were listened to by at least two different people. The sound clip identity was unknown to remove bias. The participants marked down how often they heard different types of sounds (birds, mammals, insects, voices, human activity, weather) in each clip. Changes in the presence of the sound types were analyzed by comparing what was heard during the eclipse verses what happened on days before and after the eclipse (Figure 9B). Link to sound clips (https://drive.google.com/open?id=1HCHDiHe6IlQdCD034l-bRFIJcWbPz3Ld).



A. SOUND LEVEL RESULTS



B. LISTENING RESULTS (N=2 eclipse, N=13 non on 6 day[s])

Figure 9. (A) One-third octave sound levels before/after and during eclipse, and (B) change in types of sounds between eclipse and non-eclipse days

Results

At the site in HOME, sound levels around 1,000 Hz increased above the standard deviation of non-eclipse days (A), and likely relates to an increase in human voices (B). All types of biological sounds decreased (B) and at the higher frequencies (A: 10 kHz), a decrease in insects sounds likely caused this change (B).

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